香港天文台
HONG KONG OBSERVATORY

Reprint 1223

A Consensus Approach in Predicting Spring and Summer Rainfall in Hong Kong

TONG Hang-wai, CHAN Wing-hang & LEE Sai-ming

The 30th Guangdong-Hong Kong-Macao Seminar
on Meteorological Science and Technology
Guangzhou
20-22 April 2016

以共識方法預測香港春季和夏季雨量

唐恒偉　　陳永鏗　　李細明
香港天文台

摘要

香港春、夏雨季的總雨量約佔全年雨量八成，這兩季大雨頻繁可能會帶來水浸和山泥傾瀉，但如果兩季雨量都偏少則可能引致乾旱。因此春、夏雨季的雨量預報對於災害預防和水資源管理尤其重要。本文匯報一套共識方法以預測香港春、夏雨季雨量的量級。這方法考慮一系列文獻所建議的前期預報因子，再以客觀和系統性的方法進行篩選，所得出的因子會轉化為雨量量級預報，最後取其最佳共識。驗證結果顯示此方法的表現較其它預報方法優勝。

A Consensus Approach in Predicting Spring and Summer Rainfall in Hong Kong

TONG Hang-wai　CHAN Wing-hang　LEE Sai-ming
Hong Kong Observatory

Abstract

Spring and summer rainfall represents about 80% of the annual rainfall in Hong Kong. Frequent heavy rainfall in the two seasons may cause flooding and landslide, while below-normal rainfall may lead to drought. Seasonal rainfall forecasts for these two seasons are therefore particularly important to both disaster preparedness and water resource management. This paper presents a consensus approach in predicting spring and summer rainfall category in Hong Kong. A number of pre-season predictors documented in the literature were examined and screened by an objective and systematic algorithm. The selected predictors were then translated into categorical rainfall forecasts from which the best consensus was obtained. Verification results showed that this approach performed better than other forecast methods used.

1. Introduction

Disaster preparedness and water resource management rely on seasonal rainfall forecasts for informed decisions, particularly in the rainy season when excessive or insufficient rainfall can lead to contrasting issues, e.g. flooding or drought. Owing to the stochastic nature of rainfall and the high rainfall variability in this region, seasonal rainfall forecast is still a challenge even with dynamical climate modelling in recent decades. There were previous attempts by the Hong Kong Observatory (HKO) to forecast spring and summer rainfall in Hong Kong using pre-season indices [1, 2]. A recent review of these studies showed that the methods previously investigated could be modified and enhanced to provide skilful rainfall category forecasts for spring and summer. In this study, an objective and systematic algorithm to select pre-season indices and to generate a consensus category forecast is developed. Section 2 presents the data and methodology; Section 3 discusses the verification results, followed by a summary in Section 4.

2. Data and methodology

2.1 Data

Rainfall records of spring (March-May; MAM) and summer (June-August; JJA) of HKO during 1951-2015 are used for training and verification purpose. The NCEP/NCAR Re-analysis data [3] were used for computing the pre-season indices. December-January (DJ) average of the indices was considered in the formulation of MAM forecasts because February re-analysis data would not be ready by the time of forecast formulation in an operational environment. Similarly, March-April (MA) average, in addition to December-February (DJF) average, of the indices was considered for the formulation of JJA forecasts.

Hindcast and forecast data (ensemble) of ECMWF, NCEP and JMA dynamical climate models were used to examine model skills in predicting the spring and summer rainfall of Hong Kong. Tables 1a-1b show the details of model data used for MAM and JJA forecasts respectively. For each of the climate models, the average of rainfall forecasts given by the four nearest model grid points around Hong Kong was computed and the ensemble mean of this value taken as the direct model forecast for Hong Kong.

2.2 Predictors for investigation

Potential pre-season predictors and their corresponding definitions are shown in Table 2. Indices 1 to 14 represent a set of East Asian winter monsoon indices extracted from the literature. Many studies have pointed to the strong relationship between the East Asian winter monsoon and the ensuing spring rainfall and summer monsoon. Indices 15 to 17 are predictors derived from the 1951-1980 correlation maps of spring/summer rainfall and seas surface temperature (SST)/500-hPa geopotential height (gph). Index 18 is the SST index used by HKO for operational El Niño/La Niña monitoring. Indices 19-22 are predictors considered in previous HKO studies [1, 2].

2.3 Screening of the predictors

Not all the potential predictors correlate well with spring/summer rainfall in Hong Kong.

In addition, the correlation may change in time (either improving or deteriorating) and even in sign. To screen out poor predictors and deal with possible changing correlation, a stability requirement on the running 30-year correlation (r) between the predictor and the predictand was imposed. Values of r in the previous five years were considered. If the absolute value of the average of these five values was 0.2 or above, then the predictor would be selected. For years 1981 to 1984 in the verification in Section 3.2, the number of values of r considered was one to four correspondingly.

2.4 Translating the predictors to seasonal rainfall

Seasonal rainfall forecasts were generated or translated from the selected predictors using three methods: linear regression, quantile-quantile mapping (QQM), and standardized anomaly mapping (SAM). In QQM, the relative position of the predictor in a training data set was first determined. The value of the predictand with the same position in the predictand's training data set was then taken as the forecast. In SAM, the standardized anomaly of the predictor with reference to a climatological period of 30 years was taken as the standardized anomaly forecast of the predictand.

To cater for the possible effects of climate change, the training data set was shifted in accordance with the climatological period. For example, with 1971-2000 as the climatological period and 2004 being the year to verify, the training data period would be 1971-2003; and with 1981-2010 as the climatological period and 2014 being the year to verify, the training period would be 1981-2013.

Seasonal forecasts for the public are usually framed in broad categorical terms, i.e. either "normal to below-normal" or "normal to above-normal" rainfall. Quantitative rainfall forecasts in terms of standardized anomaly generated by all three forecast methods were as such converted to category forecast through the following procedures:

(i) normal to below-normal (NB) for negative anomaly; or
(ii) normal to above-normal (NA) if otherwise.

2.5 Consensus category forecast

To integrate the category forecasts generated from the selected predictors, a simple consensus approach was adopted, i.e. voting. The consensus category forecast was determined through the following procedures:

(i) NB if the number of members for NB > half of the ensemble size; or
(ii) NA if the number of members for NA > half of the ensemble size; or
(iii) category forecast based on the ensemble mean if otherwise.

2.6 Consensus quantitative forecast

A quantitative forecast could also be derived from the ensemble based on a set of conditions prescribed for the resultant consensus. A composite of forecast standardized anomalies consistent with the consensus category forecast was computed using the following procedures:

(i) mean of those standardized anomalies ≤ 0.5 for consensus category forecast suggesting NB; or
(ii) mean of those standardized anomalies ≥ -0.5 for consensus category

forecast suggesting NA.

2.7 Dynamical climate model forecasts

Direct model forecasts given by ECMWF, NCEP and JMA are known to have significant dry bias in both spring and summer and hence need to be calibrated before a fair comparison of skill can be made. In our study, the calibration was done by invoking the three methods mentioned in Section 2.4. The calibrated model forecasts also went through the voting procedures described in Section 2.5 in order to come up with a category forecast. Since hindcast data of the dynamical climate models were only available since around 1980, model data before 2001 were used for training purpose only, and performance of the climate models evaluated for the period 2001-2015.

3. Results

3.1 Most selected predictors

For MAM rainfall forecasts, the four most selected predictors (DJ-averaged) are: I_WangChen, MSLP, Z500GL and Z500rf (Table 3). I_WangChen is an East Asian winter monsoon index and MSLP a proxy of the strength of the winter monsoon affecting southern China. Studies have shown how variations in East Asian winter monsoon can influence the climate in subsequent seasons [4]. Z500GL is the average 500-hPa gph around Greenland, which is an indicator of a possible connection between the North Atlantic Oscillation (NAO) and spring rainfall in southern China [5]. Z500rf is derived from past correlation between 500-hPa gph and MAM rainfall in Hong Kong.

For JJA rainfall forecasts, the three most selected predictors (DJF-averaged) are: I_UMI, I_Ji and I_sst_JJA (Table 3). Both I_UMI and I_Ji are winter monsoon indices, albeit designed for different regions. According to Yan *et al.* [6], anomalous East Asian winter monsoon may have persistent impact on the sea surface temperature of the South China Sea which in turn influences the land-sea thermal contrast in summer. I_sst_JJA is derived from past correlation between SST and JJA rainfall in Hong Kong. Figure 1 shows the running 30-year correlation of the most selected MAM and JJA predictors during 1981-2015.

3.2 Verification results for Hong Kong

Performance of the consensus category forecast was compared to three reference forecasts with no skills: random forecast, persistent “normal to below-normal” (NB) forecast, and persistent “normal to above-normal” (NA) forecast. Since the category forecast is formulated in either NB or NA, a random forecast has about 70% chance of being correct. Tables 4a-4b summarize the number of correct MAM and JJA category forecasts given by different methods. The consensus method is the best performer during 1981-2015, scoring 27 springs and 29 summers out of 35 years. The consensus method also beats the calibrated model forecasts during 2001-2015.

Root-mean-squared-error (RMSE) is used as a metric for assessing the performance of quantitative forecasts. Tables 5a-5b show the RMSE of MAM and JJA forecasts given by different methods. For JJA forecasts, the consensus method has an advantage over climatology and performs much better than dynamical climate models.

Figure 2 shows the consensus quantitative forecasts against actual observations standardized rainfall anomalies for MAM and JJA. On a number of occasions, the consensus forecasts have got the anomaly signs correct but the forecast anomalies are not large enough to capture the magnitudes of the fluctuating changes.

4. Summary

An objective and systematic algorithm was developed to utilize pre-season indices to generate consensus category forecasts for spring and summer rainfall in Hong Kong. Verification results showed that the consensus category forecast was sufficiently skilful as compared against other methods, and out-performed calibrated dynamical climate model forecasts in both seasons. The consensus method also performed better than calibrated model forecasts in quantitative terms during summer. Further studies would be required to fine-tune the consensus quantitative forecasts to adequately reflect the large fluctuations in spring and summer rainfall in Hong Kong.

References

[1] Bell, G. J., 1976: Seasonal forecasts of Hong Kong summer rainfall. *Weather*, Vol. **31**, No. **7**, 208-212.

[2] Kung, W. H., 2001: Seasonal forecasting of rainfall in Hong Kong, Part I: Spring rainfall. *Hong Kong Observatory internal report*.

[3] Kalnay and coauthors, 1996: The NCEP/NCAR 40-year reanlaysis project, *Bull. Amer. Meteor. Soc*., **77** 437-470

[4] R. G. Wu and B. P. Kirtman, 2007: Observed relationship of spring and summer East Asian rainfall with winter and spring Eurasian snow. *J. Climate*. **20**, 1285-1304

[5] Zhou, T. B., 2013: Weakening of winter North Atlantic oscillation signal in spring precipitation over southern China. *Atmos. Oceanic Sci. Lett*. **6(5)**, 248-252

[6] Yan, H. M., H. Yang, Y. Yuan and C. Y. Li, 2011: Relationships between East Asian winter monsoon and summer monsoon. *Adv. Atmos. Sci.* **28(6)**, 1345 - 135

[7] Lu, E. and J. C. L. Chan, 1999: A unified monsoon index for South China. *J. Climate* **12**, 2375-2385

[8] Chen W., H. F. Graf and R. H. Huang, 2000: The interannual variability of East Asian winter monsoon and its relation to the summer monsoon. *Adv. Atmos. Sci.*, 46-60

[9] Chen, J. and S. Q. Sun, 1999: East Asian winter monsoon anomaly and variation of global circulation. Part I: A comparison study on strong and weak winter monsoon. *Chinese J. Atmos. Sci*., **23**, 101-111

[10] Gong, D. Y., S. W. Wang and J. H. Zhu, 2001: East Asian winter monsoon and Arctic Oscillation. *Geophys. Res. Lett.,* **28**, 2073-2076

[11] Guo, Q. Y., 1994: Relationship between the variations of East Asian winter monsoon and temperature anomalies in China. *Quarterly Journal of Applied Meteorology*, **5**, 218-225. (in Chinese)

[12] Hu, Z. Z., L. Bengtsson and K. Arpe, 2000: Impact of global warming on the Asian winter monsoon in a coupled GCM. *J. Geophys. Res*., **105**, 4607-4624

[13] Jhun, J. G., and E. J. Lee, 2004: A new East Asian winter monsoon index and associated characteristics of the winter monsoon. *J. Climate*, **17**, 711-726

[14] Ji, L. R., S. Q. Sun, K Arpe and L. Bengtsson, 1997: Model study on the interannual variability of Asian winter monsoon and its influence. *Adv. Atmos. Sci*, **14(1)**, 1-22

[15] Shi, N., 1996: Features of the East Asian winter monsoon intensity on multiple time scale in recent 40 years and their relation to climate. *Quarterly Journal of Applied Meteorology*, **7**, 175-182 (in Chinese)

[16] Wang, L., R. H. Huang, L. Gu, W. Chen and L. H. Kang, 2009: Interdecadal variations of the East Asian winter monsoon and their association with quasi-stationary planetary wave activity. *J. Climate*, **22**, 4860-4872

[17] Wang, L. and W. Chen, 2013: intensity for the East Asian winter monsoon. *J. Climate*, **27**, 2361-2374

[18] Wu, R. G and B. Wang, 2002: A contrast of the East Asian summer monsoon-ENSO relationship between 1962-77 and 1978-93. *J. Climate*, **15**, 3266-3279

[19] Yang, S., K. M. Lau and K. M Kim, 2002: Variations of the East Asian Jet Stream and Asian-Pacific-American winter climate anomalies. *J. Climate*, **15**, 306-325

[20] Zhu, Y. F, 2008: An index of East Asian winter monsoon applied to the description of China' s mainland winter temperature changes. *Acta Meteo. Sinica* **22(4**), 522-529

Table 1a Details of ECMWF, NCEP and JMA climate model data for MAM forecasts.

Model	Period of hindcasts (HC)/forecasts (FC)	Initial dates
ECMWF	HC: 1981-2010	1 Feb
	FC: 2011-2015	1 Feb
NCEP	HC: 1982-2010	10, 15, 20 Feb
	FC: 2011-2015	10-20 Feb
JMA	HC: 1979-2010	16, 30 Jan; 10 Feb
	FC: 2011-2015	26, 31 Jan; 5, 10 Feb

Table 1b Details of ECMWF, NCEP and JMA climate model data for JJA forecasts.

Model	Period of hindcasts (HC)/forecasts (FC)	Initial dates
ECMWF	HC: 1981-2010	1 May
	FC: 2011-2015	1 May
NCEP	HC: 1982-2010	11, 16, 21 May
	FC: 2011-2015	11-21 May
JMA	HC: 1979-2010	16 Apr; 1 May
	FC: 2011-2015	16, 21, 26 Apr; 1, 6, 11 May

Table 2 Potential pre-season indices: SLP, SST, Z, u, v denote sea level pressure, sea surface temperature, geopotential height, zonal wind and meridional wind respectively.

	Index	Brief description
1	I_UMI [7]	1000-hPa v (7.5-20 ^{o}N, 115-130 ^{o}E)
2	I_Chen [8]	10-m v: average of 10-25 ^{o}N, 110-130 ^{o}E and 25-40 ^{o}N, 120-140 ^{o}E
3	I_ChenSun [9]	1000-hPa v (15-30 ^{o}N, 115-130 ^{o}E)
4	I_Gong [10]	SLP (40-60 ^{o}N, 70-120 ^{o}E)
5	I_Guo [11]	SLP gradient (10-60 ^{o}N, 110-160 ^{o}E)
6	I_Hu [12]	10-m v (15-40 ^{o}N, 115-130 ^{o}E)
7	I_JhunLee [13]	300-hPa u: (27.5-37.5 ^{o}N, 110-170 ^{o}E) – (50-60 ^{o}N, 80-140 ^{o}E)
8	I_Ji [14]	1000-hPa v (10-30 ^{o}N, 115-130 ^{o}E)
9	I_Shi [15]	SLP gradient (20-50 ^{o}N, 110-160 ^{o}E)
10	I_Wang_b [16]	SLP gradient (40-70 ^{o}N, 110-160 ^{o}E)
11	I_WangChen [17]	SLP: 2*(40-60 ^{o}N, 70-120 ^{o}E) – (30-50 ^{o}N, 140-190 ^{o}E) – (20 ^{o}S - 10 ^{o}N, 110-160 ^{o}E)
12	I_WuWang [18]	850-hPa u: (5-15 ^{o}N, 100-130 ^{o}E) – (20-30 ^{o}N, 110-140 ^{o}E)
13	I_Yang [19]	850-hPa v (20-40 ^{o}N, 100-140 ^{o}E)
14	I_Zhu [20]	500-hPa u: (25-35 ^{o}N, 90-120 ^{o}E) – (50-60 ^{o}N, 80-120 ^{o}E)
15	I_sst_MAM	SST: (5-15 ^{o}N, 150-175 ^{o}E) – (5-25 ^{o}S, 160 ^{o}E - 170 ^{o}W), derived from the 1951-1980 correlation map of MAM rainfall and DJ SST
16	I_sst_JJA	SST: (20-30 ^{o}N, 110-125 ^{o}E) – (10-25 ^{o}N, 130^{o}E-155 ^{o}W), derived from the 1951-1980 correlation map of JJA rainfall and DJF SST
17	Z500rf	500-hPa Z: (20-40 ^{o}N, 120-150 ^{o}E) – (55-70 ^{o}N, 150-180 ^{o}E), derived from the 1951-1980 correlation map of MAM rainfall and DJ 500 hPa Z
18	NinoZ	Area weighted average of Niño 1-4 SST anomalies
19	MSLP	Mean SLP in Hong Kong
20	Z500GL	500-hPa Z (60-80 ^{o}N, 30-60 ^{o}W)
21	Sunshine	Total sunshine duration in Hong Kong
22	RF	Total rainfall in Hong Kong

Table 3 Most selected predictors for MAM and JJA forecasts

MAM forecast	I_WangChen, MSLP, Z500GL, Z500rf (all DJ-averaged)
JJA forecast	I_UMI, I_Ji, I_sst_JJA (all DJF-averaged)

Table 4a Number of correct MAM rainfall category forecasts by different methods

Years	Random	Persistent NA	Persistent NB	Consensus	Calibrated ECMWF	Calibrated NCEP	Calibrated JMA
1981-2015	~24	26	26	**27**	--	--	--
2001-2015	~10	11	13	**13**	12	12	12

Table 4b Number of correct JJA rainfall category forecasts by different methods

Years	Random	Persistent NA	Persistent NB	Consensus	Calibrated ECMWF	Calibrated NCEP	Calibrated JMA
1981-2015	~24	25	25	**29**	--	--	--
2001-2015	~10	11	12	**13**	11	12	11

Table 5a Root-mean-squared-error (RMSE) of MAM quantitative rainfall forecasts by different methods (unit in mm)

Years	Consensus	Climatology	Calibrated ECMWF	Calibrated NCEP	Calibrated JMA
1981-2015	298	299	--	--	--
2001-2015	263	218	268	254	260

Table 5b Root-mean-squared-error (RMSE) of JJA quantitative rainfall forecasts by different methods (unit in mm)

Years	Consensus	Climatology	Calibrated ECMWF	Calibrated NCEP	Calibrated JMA
1981-2015	468	476	--	--	--
2001-2015	468	472	568	607	586

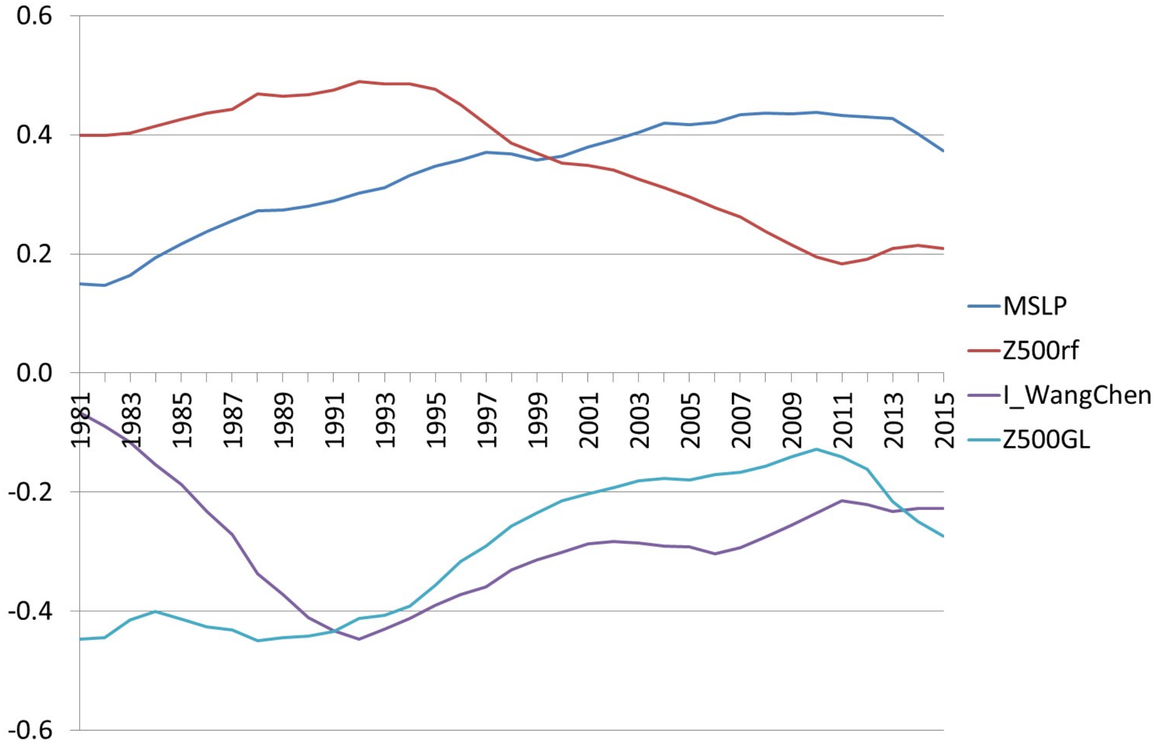

Figure 1a Running 30-year correlation between the most selected predictors and MAM rainfall in Hong Kong during 1981-2015.

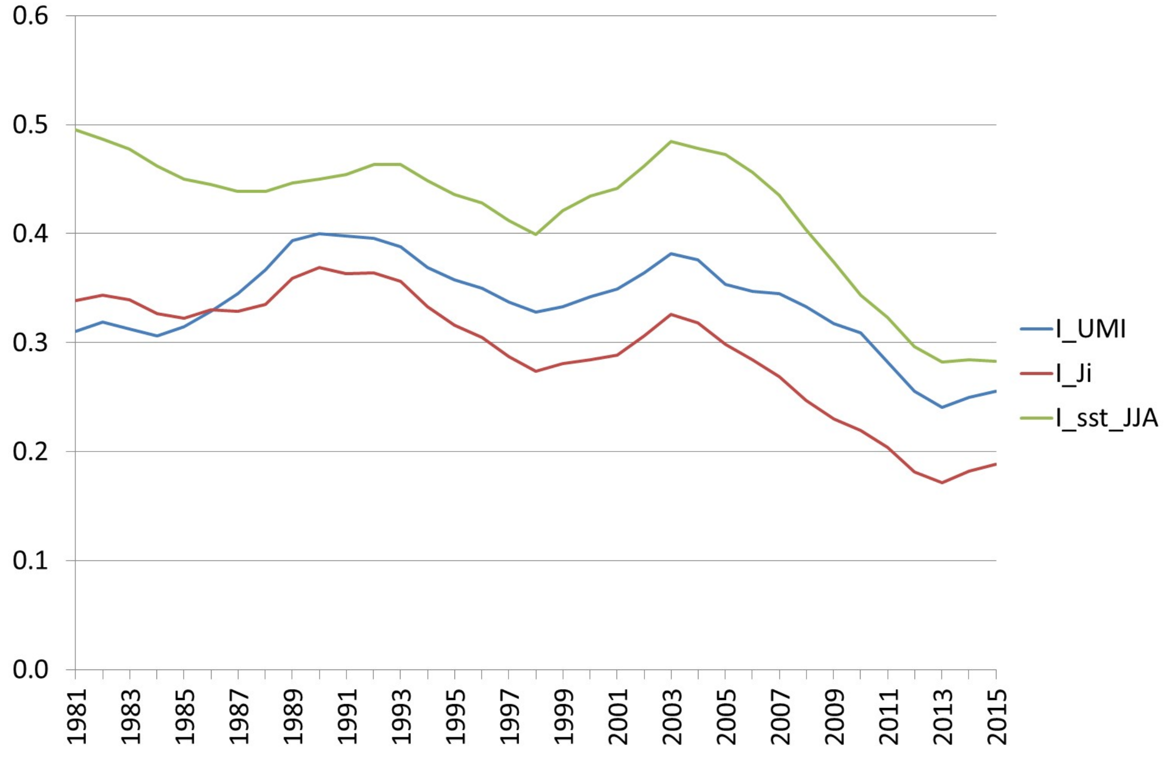

Figure 1b Running 30-year correlation between the most selected predictors and JJA rainfall in Hong Kong during 1981-2015.

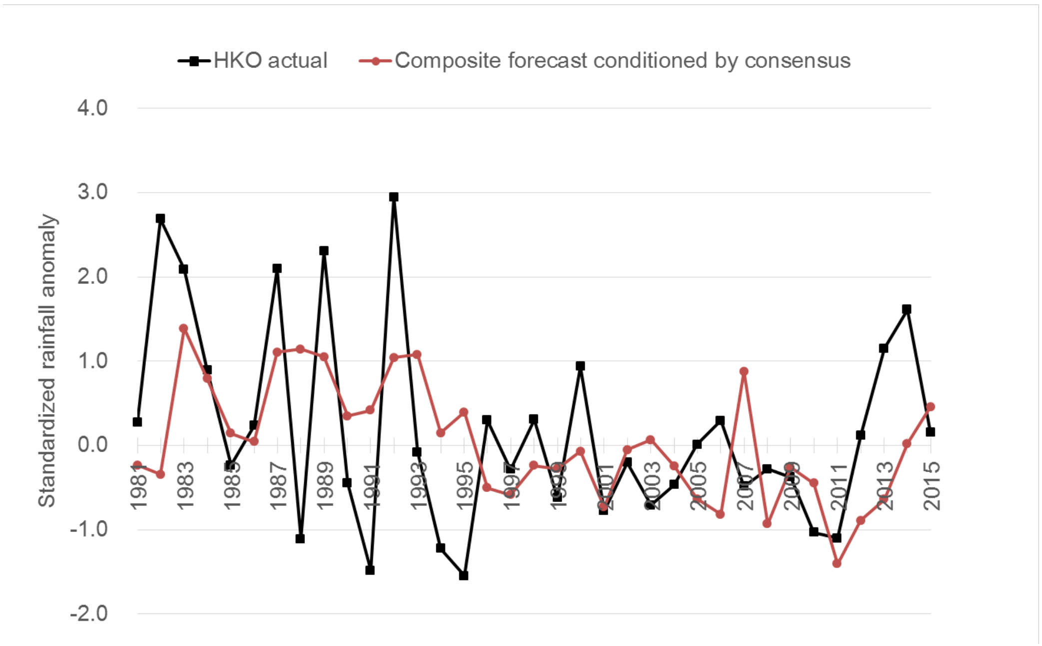

Figure 2a Standardized MAM rainfall anomaly as observed at HKO (black) and predicted by the consensus quantitative forecast (brown).

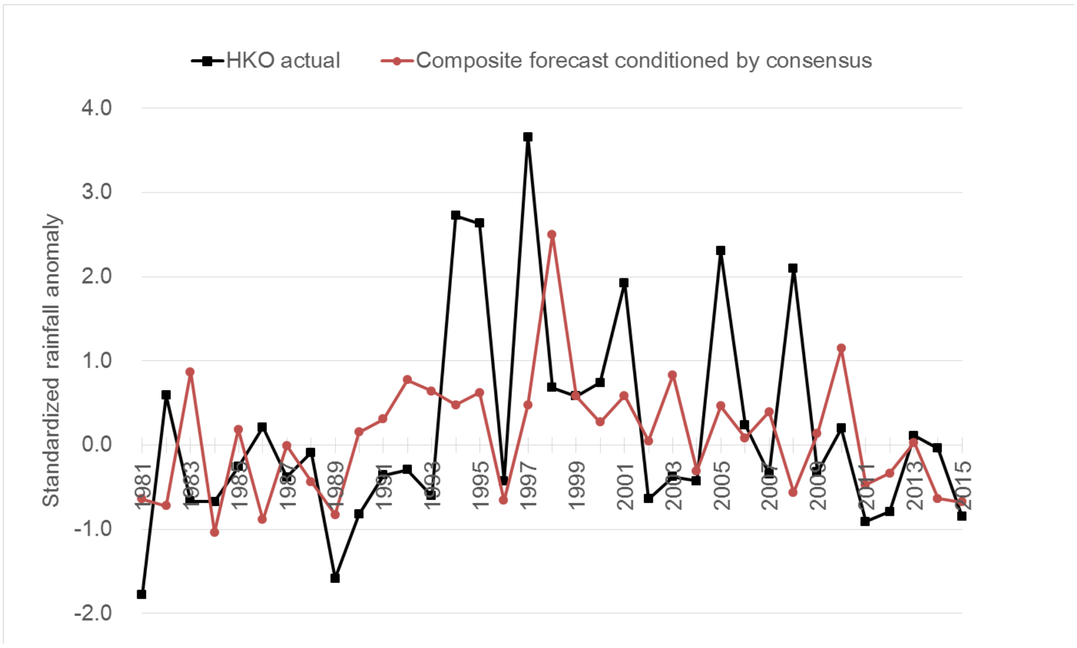

Figure 2b Standardized JJA rainfall anomaly as observed at HKO (black) and predicted by the consensus quantitative forecast (brown).